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Does changing distractor environments eliminate spatiomotor biases?

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Abstract

This research explored how sensitive spatiomotor biases, or location-response integration effects, are to differences between visual environments. According to feature integration and episodic retrieval theories, a target's location and response are integrated to form an event representation in memory. A repetition of the prior location or target response retrieves the previously associated response or location, respectively. This leads to interference or slower responding when the retrieved event information mismatches the current event. In the four experiments here, to generate these spatiomotor biases, participants discriminated serially-presented target stimuli that randomly repeated or changed location. Crucially, the visual environment of the target changed from moment-to-moment by either adding or removing distractors and placeholders. Spatiomotor biases were strong and robust across all environmental changes, with minimal to no effect of the environment on them. Thus, the spatiomotor biases generalize very well beyond the environments in which they are generated, showing that the representation of a target location and response event is not necessarily integrated with the representation of the global visual environment.

There is considerable evidence in the visual cognition literature that variance in the visual environment can modify spatial selection biases generated by recent experience. A well-known example of this can be found in the intertrial priming literature on visual search, in which it has been shown that from one visual search display to the next, people tend to identify the target stimulus more quickly when it happens to re-appear at a recently attended location relative to elsewhere (e.g., Maljkovic & Nakayama, 1996; Tanaka & Shimojo, 1996; 2000; Hilchey, Leber & Pratt, 2018). This facilitatory effect, sometimes referred to as *positive position priming* or *spatial positive priming*, is thought to reflect a bias in favor of stimulus identity processing at prior target locations. This facilitatory effect has been shown to depend strongly on the repetition of the target's position relative to the positions of other stimuli that co-occurred with it (Tower-Richardi, Leber, & Golomb, 2016; Gokce, Muller & Geyer, 2015; Geyer, Muller & Krummenacher, 2007; Ball, Smith, Ellison & Schenk, 2009; Maljkovic & Nakayama, 1996). Put another way, this positive priming is affected by changes to the environment.

Another well-known example of variance in the environment modifying biases can be found in the spatial orienting literature on visual search. When attention has been shifted to one region in the visual environment and then shifted away, people tend to detect targets more slowly when they appear at a location that was recently oriented to relative to elsewhere (e.g., Posner & Cohen, 1984; Klein, 1988; Taylor & Klein, 2000; Lupianez, 2010; Hilchey, Klein & Satel, 2014). This inhibitory effect, often referred to as *spatial negative priming* or *inhibition of return*, is thought to reflect a re-orienting or selection bias against a prior target location. This effect has been shown to depend critically on whether the environment in which it was generated stays the same (Redden, Klages & Klein, 2017; see Wang & Klein, 2010, for review).

In addition to spatial positive priming and spatial negative priming, there is a third kind of experience-based implicit spatial bias that leads to response repetition and alternation tendencies; *spatiomotor biases*. These biases, which involve the interaction of visuospatial and motor processes, are robust and demonstrably independent of the aforementioned facilitatory and inhibitory effects (e.g., Hilchey, Leber & Pratt, 2018; Hilchey, Rajsic, Huffman, Klein & Pratt, 2018). Operationally, these biases refer to the common observation that target identification responses tend to be particularly fast when both the recent target location and response repeat or both switch, relative to when only the prior target location or only the response repeats (e.g., Terry, Neill & Valdes, 1994; Hommel, 1998; 2005; Taylor & Donnelley, 2002; Hommel, Proctor & Vu, 2004; Hazeltine, Akcay & Mordkoff, 2011; Mordkoff, 2012; Spapé & Hommel, 2014; Hilchey, Rajsic, Huffman & Pratt, 2017a; 2017b; 2018).

These spatiomotor biases are accounted for generally by feature integration and episodic retrieval theories (e.g., Hommel, Proctor & Vu, 2004). The preferred explanation is that recent information that was relevant for successfully identifying the target stimulus, including its location and the response to it, becomes linked together implicitly in memory, forming a common representation, or “event file” (Huffman, Hilchey & Pratt, 2018; Colzato, Raffone & Hommel, 2006). When a second target that occurs some time later has something (e.g., location, response/form) in common with the prior event, information associated with the prior event is retrieved. This can be problematic if the retrieved information is only partially consistent with the current event. In such cases, there is a so-called “partial mismatch”, which leads to interference, and consequently, slower reactions (Hommel, 2004; Memelink & Hommel, 2013). Applied to the spatiomotor biases, if the target location repeats, the response recently associated with it is also retrieved. This leads to interference if the retrieved response does not match the

required response. Likewise, if the target response repeats, the location recently associated with it is also retrieved, and interference results if the retrieved location does not match the required location (Hommel, 1998; 2005; 2007; Hilchey et al., 2017b).

If spatial positive and negative priming effects are sensitive to environmental changes, is the same true of spatiomotor biases? That is, more theoretically, does the integrated representation of the location and response critically include environment? To answer this, we report data from four experiments in which we manipulate the presence and absence of visual distractors to create changes across environments. From one visual display to the next, a to-be-identified target shape either co-occurs with five homogenous distractor stimuli, forming an imaginary circle with the target centred on fixation, or without homogeneously-shaped distractor stimuli.

If the event representation of the target location and response is linked to the environment in which it was generated, the spatiomotor biases should vanish or become much smaller when switching between visual displays with and without distractors (i.e., a mismatch between the environments). If these effects generalize across environments, a mismatch between the visual displays should not matter. By pursuing this line of investigation, we are working toward a resolution of something that Spapé and Hommel (2014) have identified as one of the “greater challenges” (p. 14), which involves determining when and whether contextual discontinuities reduce feature integration and episodic retrieval effects.

Experiment 1

This experiment tested whether changes between visual environments modify the spatiomotor biases. To accomplish this, each trial consisted of an initial target display (T1) followed by a second target display (T2) one second after the response to T1. Throughout the trial, a white circle remained at screen centre, on which the eyes were to be fixated. The target was a white circle with a gap on either its left or right side, which was identified with one of two keypress responses. The target appeared randomly at one of six marked (placeholder) locations that were arranged to form an imaginary circle centred on fixation. In this experiment, T1 randomly contained either: 1) the target with no distractors or 2) the target with 5 white distractor ‘+’ signs. T2 likewise randomly contained the target accompanied by no or 5 white distractors. The key question addressed by this experiment was whether or not spatiomotor biases were reduced or eliminated by adding or removing distractors between target displays. It is worth noting that on a small subset of the trials, instead of T2, a small to-be-discriminated digit (2 or 9) briefly appears at fixation. This digit can only be identified if both the eyes and attention are focused on fixation. The purpose of this rare digit event is two-fold: 1) to help ensure that any attention allocated to the target in T1 returns to centre by the time of T2, and 2) to reduce the likelihood of eye movements to stimuli in the visual periphery.

Method

Participants. Twenty-one undergraduate students from the University of Toronto consented to participate for course credit or monetary compensation until the experiment was over or 90 minutes had elapsed.

Stimuli and Apparatus. Stimuli were displayed on 24" LED monitors connected to Dell computers running a custom Python program. A chinrest 57 cm from the monitor was used to stabilize head position. Responses were made with the “z”, “/”, “2”, “9” and spacebar keys on standard QWERTY keyboards. All stimuli were displayed against a black (RGB: 0, 0, 0) background. A small white (RGB: 0, 0, 0) filled circle (radius = 0.15° of visual angle) at screen centre served as a fixation stimulus. The six-possible target and distractor locations were marked by grey (RGB: 128, 128, 128) outline (1-pixel linewidth) placeholder circles (radius = 1.25°), spaced evenly apart and centred 5° of visual angle away from fixation. The target was a white outline circle (radius = 0.625° ; 2 pixel linewidth) with a large gap in it, accounting for 1/6 of its circumference, that was centred on its left- or right-most point. The distractors were white “+” signs ($1.25^\circ \times 1.25^\circ$; 2 pixel linewidth). The small digits at fixation were white 2s and 9s, formed by straight lines that were 0.10° in length. The pattern mask consisted of 125 filled white squares ($0.10^\circ \times 0.10^\circ$) whose centres appeared randomly within an imaginary $0.70^\circ \times 0.70^\circ$ square at screen centre. Response ‘Error’ messages appeared at screen center in white font.

Procedure. A couple of possible trial sequences are illustrated in Figure 1. Each trial begins with the fixation stimulus, the placeholder circles and a spacebar response, which is made when the participant is ready. The first target display (T1) appears 500 ms later. T1 consists of the target at a random placeholder location and randomly either 5 distractors at the remaining placeholder locations or 0 distractors. A “z” or “/” keypress response is made to identify whether the target circle’s gap is on the left or right side, respectively. On 87.80% of trials, T2 appears 1 second after the response to T1. Like T1, T2 also consists of the target at a random placeholder location and randomly either 5 distractors at the remaining placeholder locations or 0 distractors and the target is identified with the corresponding key. On 12.20% of trials, instead of T2, a small digit (2 or 9) appears at fixation for 100 ms, after which its identity is obscured by the pattern mask. A non-speeded “2” or “9” keypress is made to identify the digit. If all trial responses are correct, the screen turns black for 1 s. Otherwise, the “Error” message appears, which is acknowledged with a spacebar response, and then the screen turns black for 1 s.

The experiment consists of 984 experimental trials, preceded by 20 practice trials. This experimental trial count corresponds with all combinations of Target Location 1 (6 levels) x Target Location 2 (6 levels) x Distractor Set Size 1 (0 or 5) x Distractor Set Size 2 (0 or 5) x Target Shape/Response Repetition (same or different) x 3, plus Target Location 1 (6 levels) x Distractor Set Size 1 (0 or 5) x target digit (2 or 9).

Results

Descriptives and exclusions. The mean participant error rate for number discrimination at fixation was 9.68% ($SD = 8.02\%$; range = 0.00 - 25.00%), with no participants exceeding the exclusion criterion ($> 30\%$ errors). Prior to the RT analyses, trials with unreasonably long target-target onset asynchronies (> 5 s) were excluded, accounting for 7 trials. Trials with response errors to T1 (M participant error rate = 2.56%; $SD = 1.74\%$; range = 0.41% - 7.83%) were excluded. Next, trials with unreasonably fast (< 200 ms; 7 trials) and slow (> 2 s; 43 trials) responses to T2 were excluded as anticipatory and evidence of disengagement from the task, respectively. Of the remaining data, trials with response errors to T2 (M participant error rate = 3.67%; $SD = 2.20\%$; range = 0.81% - 9.37%) were excluded. Note that this low error rate prohibited any meaningful statistical analyses on errors here and elsewhere, as they were simply too sporadic across participants and the full range of conditions in the design. Finally, z-scores were computed for each participant's RTs to detect outliers (z scores > 2.5) at each level of Distractor Set Size 2; this led to the exclusion of 2.76% of the remaining data.

RT Analyses. The mean RTs for all conditions have been illustrated in Figure 2. Mean participant RTs were submitted to a 2 (Target Location Repetition: Same or different) \times 2 (Target Shape/Response Repetition: Same or different) \times 2 (Distractor Set Size 1: 0 or 5) \times 2 (Distractor Set Size 2: 0 or 5) repeated measures ANOVA.

Main effects. There were effects of Target Location Repetition, $F(1, 20) = 25.79, p < 0.01, \eta_p^2 = 0.5632$, Target Shape/Response Repetition, $F(1, 20) = 120.50, p < 0.01, \eta_p^2 = 0.8577$, Distractor Set Size 2, $F(1, 20) = 127.10, p < 0.01, \eta_p^2 = 0.8640$, but not of Distractor Set Size 1, $F(1, 20) = 0.04, p = 0.843, \eta_p^2 = 0.0020$. Responses were faster when the target location repeated

(521 ms) instead of switched (539 ms). Responses were faster when the Target Shape/Response repeated (507 ms) instead of switched (553 ms). Responses were faster when there were no distractors (515 ms) instead of five distractors (545 ms) in the second target display.

Effects of the environment on spatial and spatiomotor biases. The effect of Target Location Repetition was qualified by all three second order interactions. Target Location Repetition strongly interacted with Target Shape/Response Repetition, $F(1, 20) = 189.70$, $p < 0.01$, $\eta_p^2 = 0.9046$. These are the spatiomotor biases; repeat responses were facilitated when the target location repeated (481 ms) instead of switched (532 ms). Alternation responses were facilitated when the target location switched (545 ms) instead of repeated (561 ms). Target Location Repetition interacted with Distractor Set Size 1, $F(1, 20) = 7.149$, $p = 0.015$, $\eta_p^2 = 0.2633$. Repeating the target location was more advantageous if there were 5 distractors in T1 (518 ms versus 542 ms when the location switched) instead of no distractors in T1 (525 ms versus 536 ms). Target Location Repetition also interacted with Distractor Set Size 2, $F(1, 20) = 8.906$, $p < 0.01$, $\eta_p^2 = 0.3081$. Repeating the target location was more advantageous if there were 5 distractors in T2 (533 ms versus 557 ms) instead of no distractors in T2 (510 ms versus 520 ms). None of the three-way interactions involving Target Location Repetition were significant (all F s < 1).

In terms of the critical four-way interaction for testing an effect of environment on the spatiomotor biases, the interaction was absent but perhaps not convincingly so, $F(1, 20) = 3.162$, $p = 0.091$, $\eta_p^2 = 0.1365$. Indeed, by comparing the bottom left and top right panels to the top left and bottom right panels in Figure 2, the spatiomotor biases were a little bit smaller when there was a mismatch between the distractor set sizes of T2 and T1. Importantly, in each panel of Figure 2, the spatiomotor biases were significant (all p s < 0.01) and large in effect (minimum η_p^2

= 0.6157 at set size 1 = 5 and set size 2 = 0; $\eta_p^2 = 0.6987$ at set size 1 = 0 and set size 2 = 5; $\eta_p^2 = 0.7337$ at set size 1 = 5 and set size 2 = 5; maximum $\eta_p^2 = 0.8057$ at set size 1 = 0 and set size 2 = 0). Any effect of the environment on the spatiomotor biases was decidedly relatively weak.

Effects of the environment on other biases. There were a handful of interactions unrelated to the spatial biases that warrant mention. Target Shape/Response Repetition interacted with Distractor Set Size 2, $F(1, 20) = 4.745, p = 0.042, \eta_p^2 = 0.1918$. Repeating the Target Shape/Response led to even faster responses when there were no distractors in T2 (489 ms versus 541 ms when target shape/response switched) instead of 5 distractors (524 ms versus 565 ms) in T2. There was also a relatively weak interaction between Distractor Set Size 1 and Distractor Set Size 2, $F(1, 20) = 4.016, p = 0.059, \eta_p^2 = 0.1672$. These weak interactions were qualified by a relatively strong three-way interaction, $F(1, 20) = 14.79, p < 0.01, \eta_p^2 = 0.4250$. This three-way interaction occurred because repeating the prior Target Shape/Response was generally more advantageous when the distractor set size also repeated (size 0 to 0 = 62 ms advantage; 5 to 5 = 50 ms; 0 to 5 = 42 ms; 5 to 0 = 32 ms). In other words, repeating the environment led to bigger response time advantages for repeating the target shape. None of the remaining interactions were significant (all F s < 1).

Discussion

The spatiomotor biases were reliable, large in effect size, and qualitatively similar across environments. While there was some evidence that the spatiomotor biases depended on the environment, the critical four-way interaction was only marginally significant and the related effect size was relatively weak ($\eta_p^2 = 0.1365$). Overall, the spatiomotor biases clearly generalized across the full range of environments, suggesting that the environment was at best only weakly integrated into the representation of the target location and response.

There are other spatial biases aside from that discussed above that are worth noting. Both of the interactions involving target location repetition and the number of distractors were reliable, with the overall advantage of repeating the target location being larger when distractors were present in either T1 or T2. These relationships were much weaker than the spatiomotor biases, though still relatively strong in effect (η^2 s = 0.26 – 0.31). It is conceivable that these interactions reflect the oft-discussed response-independent facilitatory and inhibitory processes that may bias attention, as noted earlier on (Tipper, Brehaut & Driver, 1990; Maljkovic & Nakayama, 1996; Kumada & Humphreys, 2002; Gokce, Muller & Geyer, 2015; Neill & Kleinsmith, 2016). For example, consistent with a response-independent inhibitory process related to attention, perhaps similar to spatial negative priming (Tipper, Brehaut & Driver, 1990), repeating the target location was more advantageous when there were 5 instead of 0 distractors in T1. This would be expected if the distractor locations in T1 were suppressed or tagged with some amount of inhibition, such that subsequent target processing would be more difficult if the target appeared at a prior distractor relative to vacant location. Consistent with a response-independent facilitatory process related to visual search (Maljkovic & Nakayama, 1996), repeating the target location was more advantageous when there were distractors – or a search – in T2.

Finally, a non-spatial bias, the well-known RT advantage associated with repeating the target shape (or stimulus-response mapping; e.g., Bertelson, 1963; Pashler & Baylis, 1991), depended on the environment, as was made clear by the relatively strong three-way interaction ($\eta^2 = 0.4250$) involving the repetition of the target shape and distractor set sizes 1 and 2. In effect, the response time advantage for repeating the prior target shape was greater when the environment repeated. The result appears to be somewhat consistent with observations of ‘distractor-response binding’ (Moeller, Hommel, & Frings, 2015; cf., Kristjansson, Ingvarsdottir

& Teitsdottir, 2008), suggesting that a target response or property can become linked to information or, apparently, a lack thereof, that co-occurs with the target.

Experiments 2A and 2B

There was very little evidence in the prior experiment for a relationship between the spatiomotor biases and the environment. However, we were neither completely convinced by the results of Experiment 1 nor do we believe that this will always be the case (e.g., Hilchey, Leber & Pratt, 2018, see footnote 2; Spape & Hommel, 2014). Accordingly, we ran these two experiments with some relatively minor procedural adjustments to try to strengthen the link between spatiomotor biases and the environment. If changes in displays affect spatiomotor biases, they should appear in one of these two experiments.

In the prior experiment, the probability that distractors would accompany the target in T1 was roughly equivalent to the probability that distractors would accompany the target in T2. This could be problematic for showing a dependency on the environment, as it has been shown that various spatial biases can be affected by the regularity with which a certain environment occurs (Geyer, Zehetleitner & Muller, 2010) and also, relatedly, by the predictable absence or presence of distractors (Geyer, Muller & Krummenacher, 2007; Guy, Buckolz & Pratt, 2004; Lupianez & Milliken, 1999). It has also been suggested that a target forming an imaginary triangular configuration with the distractors, which is common in the inter-trial priming literature on visual search, may be “salient”, and more likely to result in some kind of environment-dependent spatial bias (Geyer et al., 2010).

With these thoughts in mind, here we ran two more experiments to see whether we could induce a dependency of the spatiomotor biases on the environment. In Experiment 2A, the target is never accompanied by a distractor in T2. In Experiment 2B, the target is never accompanied

by a distractor in T1. In the displays that contained distractors, a new level of distractor set size was added. The new level has the target accompanied by two distractors, forming an imaginary equilateral triangle with the target. The impacts of this on the design are that 1) distractors are predictably absent in either T1 or T2, 2) relatedly, overall, the target environment is more often distractor-less than not, and 3) a “salient” target-distractor configuration, or environment, has been added. The design is thus biased toward an association between the distractor-less environment and the spatiomotor biases, with a potential for a salient, triangular target-distractor environment to produce a unique dependency.

Method

Participants. Twenty-three and 21 undergraduate students from the University of Toronto, in Experiments 2A and 2B, respectively, consented to participate for course credit or monetary compensation until the experiment was over or 90 minutes had elapsed.

Stimuli and Apparatus. These were the same as in Experiment 1.

Procedure. The procedure was identical to Experiment 1 with a few exceptions. In Experiment 2A and 2B, respectively, the targets in T2 and T1 were predictably unaccompanied by distractors. For the target displays that could contain distractors, a new level was added such that, by chance, the target could be accompanied by 2 distractors, always forming an imaginary triangle with the target that was centred on fixation. There were 756 experimental trials; on 14.29% of these, T2 was replaced by a small to-be-discriminated digit at fixation.

Results

Descriptives and exclusions. Three participants in Experiment 2A were excluded for error rates greater than 30% at discriminating numbers at the centre of the screen (error rates = 37%, 43% and 70%). One participant in Experiment 2B was excluded for this same reason (error rate = 49%). We presume that these participants were either unwilling or unable to consistently return their attention to centre after T1. After these exclusions, the mean error rate on number discrimination in Experiment 2A was 11.61% ($SD = 8.69\%$; range = 0.90 – 25.93%). In Experiment 2B, the mean error rate on number discrimination was 11.03% ($SD = 9.42\%$; range = 0.00 – 27.08%).

Trials with unreasonably long target-target onset asynchronies (>5 s) were excluded, accounting for 22 and 27 trials in Experiments 2A and 2B, respectively. Trials with response errors to T1 were excluded, with the mean participant error rates being 3.35% ($SD = 3.20\%$; range = 0.40% - 12.37%) and 3.48% ($SD = 2.21\%$; range = 0.40% - 9.01%) in Experiments 2A and 2B, respectively. For T2, trials with unreasonably fast (< 200 ms) responses were excluded as anticipatory, leading to the removal of 4 and 2 trials in Experiments 2A and 2B, respectively. Unreasonably slow responses (> 2 s) were excluded as disengagement from the task, leading to the removal of 42 and 69 trials in Experiments 2A and 2B, respectively. Of the remaining data, trials with response errors to T2 were excluded, with the mean participants error rates to T2 being 5.34% ($SD = 3.51\%$; range = 1.86 – 14.56%) and 4.10% ($SD = 1.97\%$; range = 0.93% - 8.53%) in Experiments 2A and 2B, respectively. Finally, z-scores were computed for each participant's RT to detect outliers at each level of Distractor Set Size 2; this led to the exclusion of 2.38% and 2.73% of the remaining data in Experiments 2A and 2B, respectively.

Experiment 2A RT Analyses: Variability in Distractor Set Size 1. The mean RTs for all conditions have been illustrated in Figure 3. Correct RTs were submitted to a 2 (Target Location Repetition: Same or different) x 2 (Target Shape/Response Repetition: Same or different) x 3 (Distractor Set Size 1: 0, 2 or 5) repeated measures ANOVA.

Main effects. There were effects of Target Location Repetition, $F(1, 19) = 12.54, p < 0.01, \eta_p^2 = 0.3976$ and Target Shape/Response Repetition, $F(1, 19) = 83.65, p < 0.01, \eta_p^2 = 0.8149$, but not of Distractor Set Size 1, $F(2, 38) = 1.918, p = 0.161, \eta_p^2 = 0.0917$. Responses were faster when the target location repeated (498 ms) instead of switched (515 ms). Responses were faster when the target shape/response repeated (481 ms) instead of switched (531 ms).

Effects of the environment on spatial and spatiomotor biases. The effect of Target Location Repetition was qualified by its relationship with Target Shape/Response Repetition, $F(1, 19) = 153.00, p < 0.01, \eta_p^2 = 0.8896$. These are the spatiomotor biases; repeat responses were facilitated when the target location repeated (450 ms) instead of switched (513 ms). Alternation responses were facilitated when the target location switched (517 ms) instead of repeated (545 ms). No other interactions involving Target Location Repetition, including the critical three-way for assessing whether repeating the environment mattered, were significant ($ps > 0.309; \eta^2s < 0.0560$). The spatiomotor biases were thus stable across environments (see Figure 3).

Effects of the environment on other biases. The remaining interaction between Target Shape/Response Repetition and Distractor Set Size 1 was significant, $F(2, 38) = 3.283, p = 0.0484, \eta_p^2 = 0.1473$. Repeating the Target Shape/Response was most advantageous when there were no distractors in either environment (0 distractors to 0 distractors = 58 ms advantage; 2 distractors to 0 distractors = 43 ms; 5 distractors to 0 distractors = 49 ms).

Experiment 2B: Variability in Distractor Set Size 2. The mean RTs for all conditions have been illustrated in Figure 4. Correct RTs were submitted to a 2 (Target Location Repetition: Same or different) x 2 (Target Shape/Response Repetition: Same or different) x 3 (Distractor Set Size 2: 0, 2 or 5) repeated measures ANOVA.

Main effects. There were effects of Target Location Repetition, $F(1, 20) = 14.04, p < 0.01, \eta_p^2 = 0.4125$, Target Shape/Response Repetition, $F(1, 20) = 30.98, p < 0.01, \eta_p^2 = 0.6077$ and Distractor Set Size 2, $F(2, 40) = 35.05, p < 0.01, \eta_p^2 = 0.6367$. Responses were faster when the target location repeated (535 ms) instead of switched (545 ms). Responses were faster when the target shape/response repeated (526 ms) instead of switched (553 ms). Responses were faster when there were no distractors (516 ms) instead of 2 (545 ms) or 5 (559 ms).

Effects of environment on spatial and spatiomotor biases. The effect of Target Location Repetition interacted with Target Shape/Response Repetition, $F(1, 20) = 70.37, p < 0.01, \eta_p^2 = 0.7787$, revealing the spatiomotor biases. Repeat responses were facilitated when the target location repeated (504 ms) instead of switched (549 ms). Alternation responses were facilitated when the target location switched (541 ms) instead of repeated (566 ms). The interaction involving Target Location Repetition and Distractor Set Size 2 was not significant, $F(2, 40) = 0.165, p = 0.848, \eta_p^2 = 0.0082$.

The critical three-way interaction for assessing whether repeating the environment mattered was marginal, $F(2, 40) = 3.077, p = 0.0572, \eta_p^2 = 0.1333$. As shown in Figure 4, the spatiomotor biases were significant (all $ps < 0.01$) and strong in effect across all environments (minimum $\eta_p^2 = 0.5767$ at set size 2 = 2; $\eta_p^2 = 0.7365$ at set size 2 = 0; maximum $\eta_p^2 = 0.7439$ at set size 2 = 5). However, the spatiomotor biases were a bit weaker when there were 2 distractors in T2 instead of 0 or 5. Be this as it may, the spatiomotor biases clearly generalized across the

full range of environments, even though we are increasingly confident that there can be relatively weak effects of the environment on these spatiomotor biases.

Effects of environment on other biases. The remaining interaction between Target Shape/Response Repetition and Distractor Set Size 2 was significant, $F(2, 40) = 11.85$, $p < 0.01$, $\eta_p^2 = 0.3720$. Repeating the Target Shape/Response was most advantageous when there were no distractors in either environment (0 distractors to 0 distractors = 42 ms advantage; 0 distractors to 2 distractors = 14 ms; 0 distractors to 5 distractors = 26ms).

Discussion

The spatiomotor biases are consistent with those found in Experiment 1. The spatiomotor biases were reliable, large in effect size, and qualitatively similar across every condition in these experiments. Once again, there was only limited evidence that the spatiomotor biases were influenced by the environment. The critical three-way interaction for assessing whether repeating the distractor-less display matter was nowhere near significant in Experiment 2A and was marginally significant, though relatively weak ($\eta_p^2 = 0.1333$), in Experiment 2B. The “salient” triangular configuration formed by the target and distractors at T2 (Experiment 2B), but not T1 (Experiment 2A), weakly diminished the spatiomotor biases. Increasing the number of distractor-less trials and the predictable absence of distractors did not result in the spatiomotor biases becoming associated with a distractor-less environment, as the biases were virtually identical regardless of whether there were 0 or 5 distractors in the target displays. All and all, again, the evidence suggests that the environment was at best only weakly linked to the representation of the prior target location and response.

There were other findings not central to our main question, but pertaining to other aspects of spatial biases, that should be mentioned. Unlike in Experiment 1, Experiment 2A revealed

little convincing evidence of inhibition at the distractor locations. If present, there should have been an interaction between Target Location Repetition and Distractor Set Size 1, with the advantage of repeating the target location increasing as a function of the number of distractors in T1. The absence of an interaction seems consistent with the observations that the predictable absence of a distractor in T2 can eliminate or mask distractor inhibition (Guy, Buckolz & Pratt, 2004). Furthermore, unlike in Experiment 1, a greater number of distractors in T2 in Experiment 2B did not increase the advantage of repeating the prior target location, which is inconsistent with a response-independent facilitatory effect related to visual search.

Finally, the modification of the target shape/response repetition effect by Distractor Set Size 1 and Distractor Set Size 2 in Experiments 2A and 2B, respectively, remains consistent with the results of Experiment 1. Repeating the target was most advantageous whenever the environment repeated, which in Experiments 2A and 2B simply meant that the target was unaccompanied by distractors in T1 and T2.

Experiment 3

So far, despite our best efforts, we have obtained only very limited evidence that the spatiomotor biases depend on the environment, with the partial η^2 s for the critical relationships always being less than 0.15. Across all cases, the spatiomotor biases have been amongst the strongest effects, with η_p^2 s always exceeding 0.55. What else might be needed to show a strong dependency of the spatiomotor biases on the environment?

Recall that in our prior experiments there were always six faint placeholder circles in the environment, which marked the potential target and distractor locations and were consistently arranged to form an imaginary circle about fixation. Perhaps in the prior experiments the spatiomotor biases instead became strongly linked to the placeholder environment, which

represented the most regularly occurring configuration or layout. If so, a dependency on the environment may not have been expected, as the omnipresent placeholder arrangement may have been prioritized over the more sporadic target-distractor arrangements for the reference frame of the spatiomotor biases (e.g., Geyer, Zehetleitner & Muller, 2010).

Furthermore, dramatically changing the arrangement of stimuli from one moment to the next can abolish phenomena like spatial negative priming (Redden, Klages & Klein, 2017) and spatial positive priming (Gokce, Muller & Geyer, 2013). Accordingly, Experiment 3 tests a new factor; the presence or absence of the visual placeholder environment. This was done by having the entire placeholder arrangement disappear with the target and distractors after the response to T1 on some trials. To accommodate this factor, we reverted to the design of Experiment 1 and reduced the number of possible target and distractor locations from six to four by removing the top- and bottom-most placeholders. If the spatiomotor biases became associated with the placeholder environment instead of any environment formed by the targets and distractors, the spatiomotor biases should be reduced, if not eliminated, by removing the placeholder environment.

Method

Participants. Twenty-six undergraduate students from the University of Toronto consented to participate for course credit or monetary compensation until the experiment was over or 90 minutes had elapsed.

Stimuli and Apparatus. These were the same as in Experiment 1, except the number of marked target and distractor placeholder locations was reduced from 6 to 4 to form an imaginary rectangle centred on fixation (i.e., the top-most and bottom-most placeholders were eliminated).

Procedure. The experiment was identical to Experiment 1 with a few exceptions. When there were distractors accompanying the target, there were 3 instead of 5, appearing predictably at the corners of an imaginary square centred on fixation. On half of the trials, the placeholder arrangement disappeared with T1. There were 848 experimental trials; on 9.43% of these T2 was replaced by a small to-be-discriminated digit at fixation.

Results

Descriptives and exclusions. Six participants in Experiment 3 were excluded for error rates greater than 30% at discriminating numbers at the centre of the screen (error rates = 31%, 34%, 35%, 35%, 36% and 50%). After these exclusions, the mean error rate on number discrimination was 6.81% ($SD = 4.81\%$; range = 0.00 – 17.50%).

Trials with unreasonably long target-target onset asynchronies (> 5 s) were excluded, accounting for 43 trials. Trials with response errors to T1 were excluded, with the mean participant error rates being 1.94% ($SD = 1.17\%$; range = 0.35% - 5.07%). No data were lost for unreasonably fast (< 200 ms) responses to T2, while 69 trials were excluded for unreasonably slower (> 2000 ms) responses to T2. Finally, z-scores were computed for each participant's RT to detect outliers at each level of Distractor Set Size 2; this led to the exclusion of 2.63% of the remaining data.

RT Analyses. The mean RTs for all conditions have been illustrated in Figure 5. Correct RTs were submitted to a 2 (Target Location Repetition: Same or different) x 2 (Target Shape/Response Repetition: Same or different) x 2 (Distractor Set Size 1: 0 or 3) x 2 (Distractor Set Size 2: 0 or 3) x 2 (Placeholder Presence at T2: Present or absent) repeated measures ANOVA.

Main effects. There were effects of Target Location Repetition, $F(1, 19) = 9.394, p < 0.01, \eta_p^2 = 0.3308$, Target Shape/Response Repetition, $F(1, 19) = 63.25, p < 0.01, \eta_p^2 = 0.7690$, and Distractor Set Size 2, $F(1, 19) = 143.70, p < 0.01, \eta_p^2 = 0.8832$. Responses were faster when the target location repeated (533 ms) instead of switched (543ms). Responses were faster when the target shape/response repeated (518 ms) instead of switched (558 ms). Responses were faster when there were no distractors (519 ms) instead of 3 (557 ms) in T2. The effect of Placeholder Presence at T2 was marginal, $F(1, 19) = 3.804, p = 0.066, \eta_p^2 = 0.1668$, with slightly slower responses when absent (535 ms) than present (541 ms). The effect of Distractor Set Size 1 was not significant, $F(1, 19) = 0, p = 0.988, \eta_p^2 < 0.0001$.

Effects of environment on spatial and spatiomotor biases. The effect of Target Location Repetition was qualified by its relationship with Target Shape/Response Repetition, $F(1, 19) = 124.10, p < 0.01, \eta_p^2 = 0.8672$, thus revealing the spatiomotor biases. There were no other second order interactions involving Target Location Repetition (all $ps > 0.255$, all $\eta_p^2s < 0.06750$). Target Location Repetition was further qualified by its three-way relationship with Distractor Set Size 1 and Distractor Set Size 2, $F(1, 19) = 7.394, p = 0.014, \eta_p^2 = 0.2801$. Repeating the target location was most advantageous when the distractor set size repeated (0 to 0 = 19 ms advantage; 3 to 3 = 15 ms; 1 to 3 = 3 ms; 3 to 1 = 4 ms). No other three-way interactions involving Target Location Repetition mattered (all $ps > 0.10$; all $\eta_p^2s < 0.1363$), including the relevant interaction between Target Location Repetition, Target Shape/Response Repetition and Placeholder Presence at T2 for assessing whether removing the placeholder arrangement modified the spatiomotor biases, $F(1, 19) = 0.367, p = 0.552, \eta_p^2 = 0.0190$.

For the higher order interactions involving Target Location Repetition, there was some marginal support for a four-way interaction with Target Shape/Response Repetition, Distractor

Set Size 2 and Placeholder Presence at T2, $F(1, 19) = 3.857, p = 0.064, \eta_p^2 = 0.1687$, but no other four-way interactions were significant (all $ps > 0.10$; all $\eta_p^2s < 0.1301$). Most importantly, an especially relevant interaction amongst Target Location Repetition, Target Shape/Response Repetition, Distractor Set Size 1 and Distractor Set Size 2 (see Experiment 1) for assessing whether repeating the distractors modified the spatiomotor biases was not significant, $F(1, 19) = 0.588, p = 0.453, \eta_p^2 = 0.0301$.

There was a significant five-way interaction, suggesting some dependency of the spatiomotor biases on the environment, $F(1, 19) = 7.904, p = 0.011, \eta_p^2 = 0.2938$. This five-way interaction can be seen relatively easily in Figure 5. Across all four panels (and 8 spatiomotor biases), the spatiomotor biases were significant (all $ps < .01$) and strong (all $\eta_p^2s > 0.4200$). However, in the top right panel specifically (Distractor Set Size 1 = 3/Distractor Set Size 2 = 0), removing the placeholders reduced the spatiomotor biases differentially depending on whether the target response repeated (solid lines) or switched (dashed lines). That said, even in this particular case, in which the physical difference between T1 and T2 was most dramatic (i.e., there was a target, three distractors and four placeholders in T1 and only a target in T2), the spatiomotor biases were strong in effect ($\eta_p^2 = 0.4951$), although much weaker than when the placeholder environment remained present in that same condition ($\eta_p^2 = 0.7791$). Ironically though, in effect, the weakest spatiomotor biases were actually observed precisely when the placeholder environment remained and when there were three distractors in both T1 and T2 ($\eta_p^2 = 0.4244$; see bottom right panel, black lines). Ultimately, the evidence suggests that the spatiomotor biases generalized easily across the full range of target displays, despite some slight alterations to the effects by differences between environments.

Effects of environments on other biases. There were three other interactions in this data set that did not involve Target Location Repetition but that should be mentioned (all other $ps > 0.10$, all $\eta_p^2s < 0.1363$). Target Shape/Response Repetition interacted with Distractor Set Size 2, $F(1, 19) = 16.11, p < 0.01, \eta_p^2 = 0.4588$. Repeating the target shape/response was least advantageous when T2 contained 3 (32 ms) instead of 0 (49 ms) distractors. Distractor Set Size 2 interacted with Placeholder Presence at T2, $F(1, 19) = 24.49, p < 0.01, \eta_p^2 = 0.5631$. Placeholder presence was inconsequential when there were no distractors in T2 (present = 518 ms vs absent = 519 ms) whereas placeholder presence slowed down responses to T2 when distractors were present (present = 565 ms vs absent 550 ms). These relationships were further qualified by the three-way interaction amongst Target Shape/Response Repetition, Distractor Set Size 2 and Placeholder Presence at T2, $F(1, 19) = 6.689, p = 0.0181, \eta_p^2 = 0.2604$. Repeating the target shape/response was least advantageous when there were distractors and placeholders in T2 (placeholders present/set size 3 RT advantage = 25 ms; placeholders absent/set size 3 RT advantage = 40 ms; placeholders present/set size 0 RT advantage = 51 ms; placeholders absent/set size 0 RT advantage = 50 ms).

Discussion

Yet again, the spatiomotor biases were reliable, large in effect size and qualitatively similar across all conditions, which included removing the placeholder arrangements between displays and transitioning between displays without distractors and with distractors. That said, there was a critical five-way interaction, with diminished spatiomotor biases when the placeholder arrangement was removed while transitioning from an environment with three distractors to no distractors. Conceivably then, these spatiomotor biases can be reduced when there are relatively extreme differences between environments (e.g., transitioning from an

environment with 4 placeholders and 3 distractors to an environment with no placeholders or distractor). Nevertheless, even in this case, the spatiomotor biases were strong ($\eta^2 = 0.4951$) and, apparently, no weaker than if the placeholder arrangement remained present between T1 and T2 and the distractor set size of 3 repeated ($\eta^2 = 0.4244$). Even if environmental changes do modify the spatiomotor biases, the biases are clearly qualitatively similar across the full range of environments that we have tested. Thus, the representation of the target location and response did not become linked to the environment, thus allowing for significant transfer.

Whereas the spatiomotor biases have been observed in every condition of every experiment, a number of other relationships that were observed in prior experiments seemed to have vanished, while others still have become apparent. Up to this point, repeating the target form was most advantageous when the distractors or lack thereof that co-occurred with it repeated (possibly consistent with ‘distractor-response bindings’). In Experiment 3, there was no clear evidence of this, as the advantage for repeating the target simply decreased with more placeholders and distractors in T2. In Experiment 1, we saw that repeating the target location was more advantageous when T1 contained distractors, consistent with the idea that the distractor locations were inhibited or suppressed. We saw no clear evidence of this in Experiment 3 or in Experiment 2A. Also in Experiment 1, we saw that repeating the target location was more advantageous when T2 contained distractors, consistent with a response-independent facilitatory process related to visual search. We saw no clear evidence of this in Experiment 3 or Experiment 2B. In fact, in Experiment 3, any response-independent advantage for repeating the prior target location depended on whether the presence or absence of distractors repeated between T1 and T2. Taken together, these discrepancies across experiments could be construed as consistent with evidence of a dynamic system that re-weights various sources of

information depending on the task and potential events (e.g., Krummenacher & Muller, 2012; Krummenacher, Muller, Zehetleitner & Geyer, 2009).

General Discussion

Spatiomotor biases are robust, powerful, and generalizable effects in typical spatial priming tasks. The goal of the present study was to determine how tolerant these biases are to environmental changes by manipulating distractor presence in the displays that generated and measured the biases. Experiment 1 demonstrated that spatiomotor biases were strong when transitioning from environments without distractors to displays with distractors, and *vice versa*, despite slight weakening by the environmental change. In theory, these findings suggested that the environment was only weakly integrated into the representation of the prior target location and response.

To push our tests further, Experiments 2A and 2B increased the frequency at which the target appeared unaccompanied by distractors and included conditions in which distractor absence could be predicted in either T2 or T1, respectively. We also added a salient target-distractor triangular configuration. The goal was to enhance any link between the spatiomotor biases through either paired associate learning (i.e., the location and response representation of the target was typically generated or measured in a distractor-less environment), bottom-up processes (i.e., the salient triangular configuration), or top-down processes (i.e., the predictable absence of distractors). Despite these manipulations, the spatiomotor biases were again powerful and qualitatively similar across the full range of environments, easily transferring between displays with and without distractors. That said, as it concerns top-down processing, these experiments show specifically that transitioning between environments has little impact on the

spatiomotor biases when a particular environment ought to be expected at a given time, not when a particular environment ought to be unexpected at a given time¹.

Finally, Experiment 3 introduced a more dramatic manipulation to increase the variability between environments by removing the placeholder arrangement in response to T1. We reasoned that in the prior experiments the location and response representation of the target may have become most strongly linked to the placeholder arrangement. We figured this because the placeholder arrangement was paired more frequently with the target location and response than any of the target-distractor arrangements. Again, however, the spatiomotor biases were strong regardless of whether the placeholder arrangement was present or absent in T2. While there was some evidence that extreme variability between the environments (i.e., a transition between a display with four placeholders, a target and three distractors to a display with only a target) could weaken the spatiomotor biases, the biases remained strong and quantitatively similar to other conditions in which there was little variance between environments (i.e., a transition between a display with four placeholders, a target and three distractors to the exact same arrangements).

Taken together, the data suggest that the spatiomotor biases are robust and can be extremely tolerant to variation between environments. Indeed, in another line of experiments, we have since demonstrated that integration effects, of which the spatiomotor biases are an instance, also transfer across more realistic city and forest scenes (Weidler, Hilchey, Pratt & Abrams, 2018). The transfer between environments is so profound that it is likely that spatiomotor biases would play a major role in most studies that require the selection of target identity information prior to the formation of a keypress response. These findings generally have major implications for the spatial priming literature, as these biases should be expected in manual response studies

¹ We thank Hermann Müller for pointing this out.

in the attentional cueing literature, the spatial negative priming literature, and the inter-trial priming literature on visual search. Needless to say, this encompasses an enormous number of studies, many of which have ignored these biases.

Beyond these experiments, we know that the spatiomotor biases can become linked to a specific object representation (Spape & Hommel, 2014) or environment created by the target-distractor arrangement (Hilchey, Leber & Pratt, 2018). So why was it so difficult to find evidence of this here? One possibility is that a particular arrangement of stimuli, making up the environment, would have to occur even more regularly for the biases to depend on the environment (Geyer, Zehetleitner & Muller, 2010; Geyer, Muller & Krummenacher, 2007). Thus, perhaps a link between the environment and a spatiomotor bias can only be learned through massive amounts of repeated exposure to the same environment. If so, ironically, it could be precisely because the spatiomotor biases were generated and measured across a range of different environments in our experiments that we had a difficult time finding evidence that the environment was integrated into the representation of the target location and response. This possibility would allow us to explain why a re-analysis of Tower-Richardi, Leber and Golomb (2016) by Hilchey, Leber and Pratt (2018; see footnote 2) revealed spatiomotor biases when the target and distractors repeated their relative positions despite not repeating their absolute environmental or retinotopic positions. In those experiments, the target-distractor environment (squares or rectangles depending on the experiment) were always the same. This may have allowed the spatiomotor biases to become linked to the specific target-distractor environments. Conceivably then, by dramatically increasing the frequency with which the target co-occurs with distractors to form a predictable configuration or by further reducing the frequency of distractors could induce a dependency of the spatiomotor bias on the environment.

While not mutually exclusive, spatiomotor biases may reside natively in action pathways that often operate independent of perception pathways, as in duplex theories of vision (Goodale & Westwood, 2004). This possibility is bolstered by prior findings showing that spatiomotor biases tend to be, at best, weakly modified by repetition of the target-defining feature (e.g., Hilchey et al., 2017a, Experiment 1; Terry, Valdes & Neill, 1994, Experiment 3; Hommel, 2005) and, as shown here, the repetition of the environment is likewise not critical. If the spatiomotor biases are native to action pathways, it is easier to understand why it has been challenging to demonstrate dependencies on the environment, as the level of representation of the spatiomotor bias would often be egocentric (Goodale & Haffenden, 1998). Nevertheless, perhaps by pairing the target even more frequently with a particular type of an environment, the spatiomotor biases could become dependent on the environment.

Conclusion

The goal of this research was to determine whether the common representation of a target location and response is critically linked to the environment in which it was generated. We could find little evidence of this. Across the four experiments, spatiomotor biases easily withstood changes in the distractors and placeholders between target displays (i.e., environmental changes). As such the spatiomotor biases show extreme transfer across many environments and are likely a major part of most spatial priming studies that require speeded keypress responses. It remains to be seen exactly what the critical ingredients are for linking spatiomotor biases to their environment.

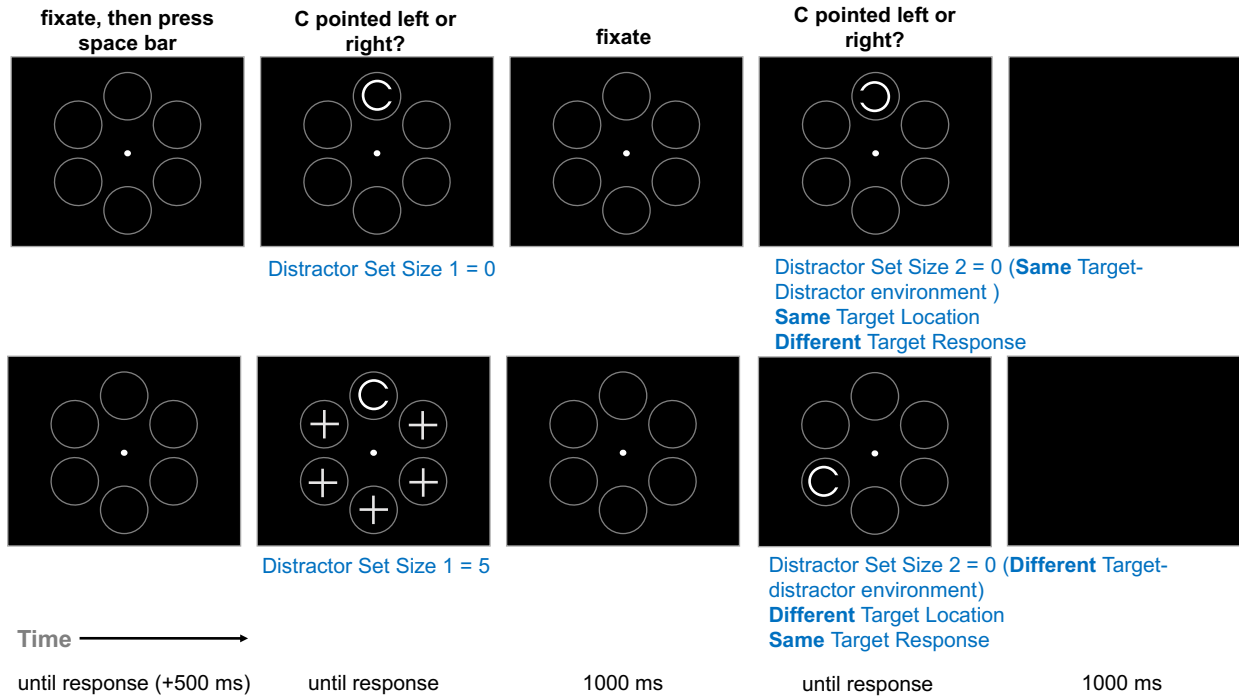


Figure 1. Two of the possible trial sequences in Experiment 1.

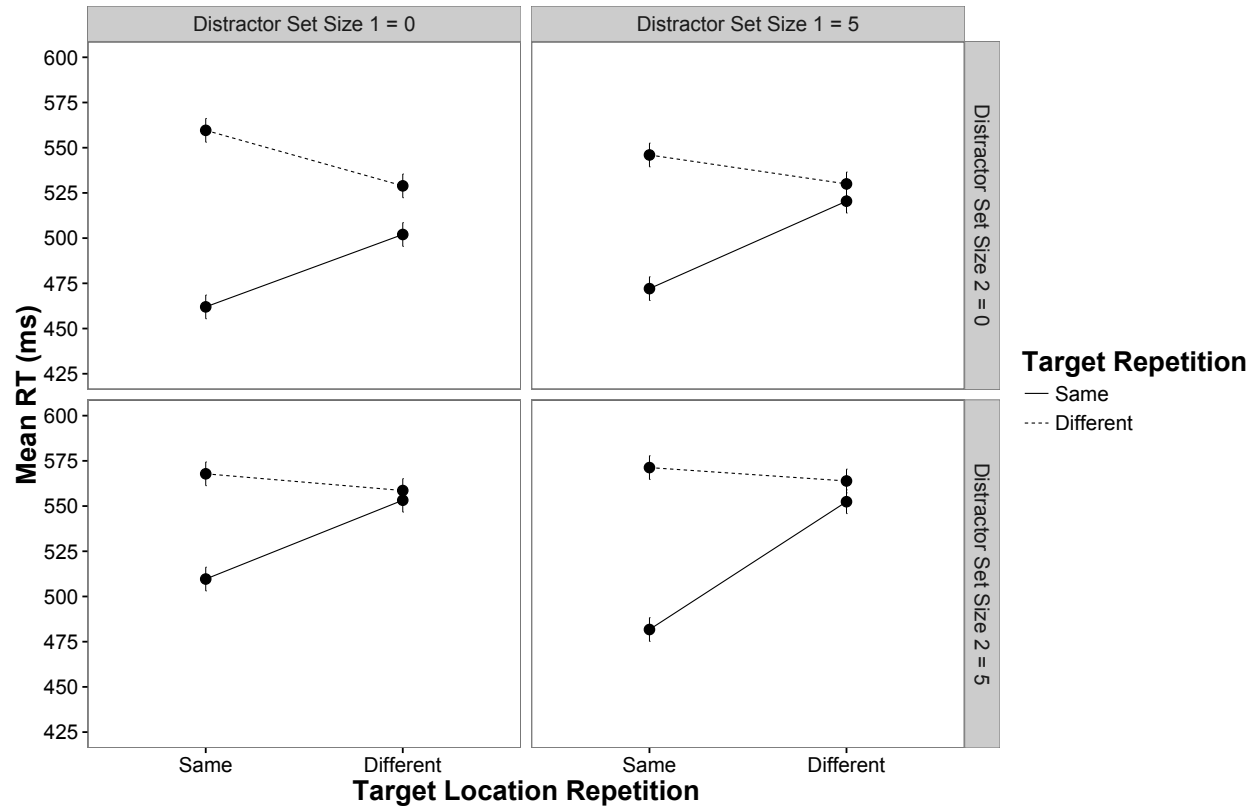


Figure 2. Mean response times (RTs) across all factorial combinations in Experiment 1. Error bars are half Fisher's least significant differences (LSDs) computed from the mean squared error term of their interaction.

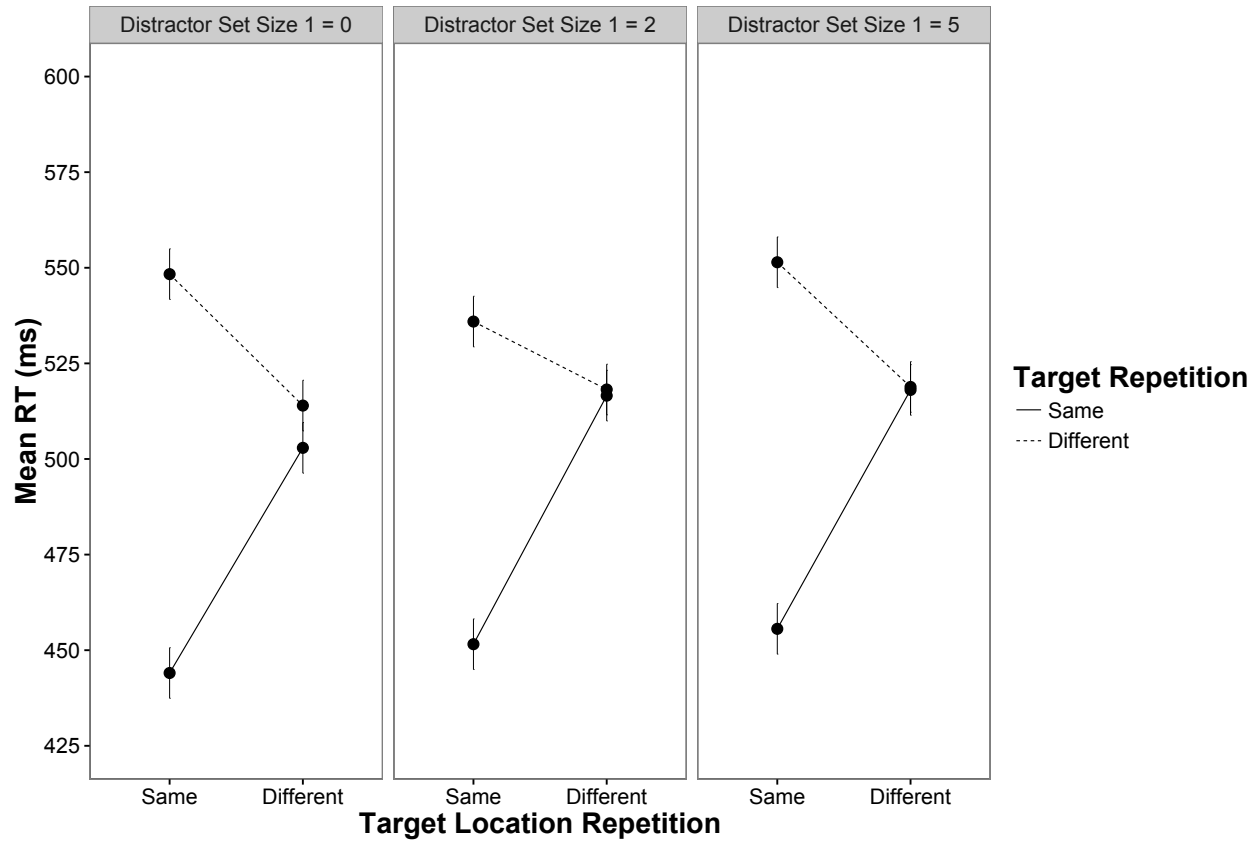


Figure 3. Mean response times (RTs) across all factorial combinations in Experiment 2A. Error bars are half Fisher's least significant differences (LSDs) computed from the mean squared error term of their interaction.

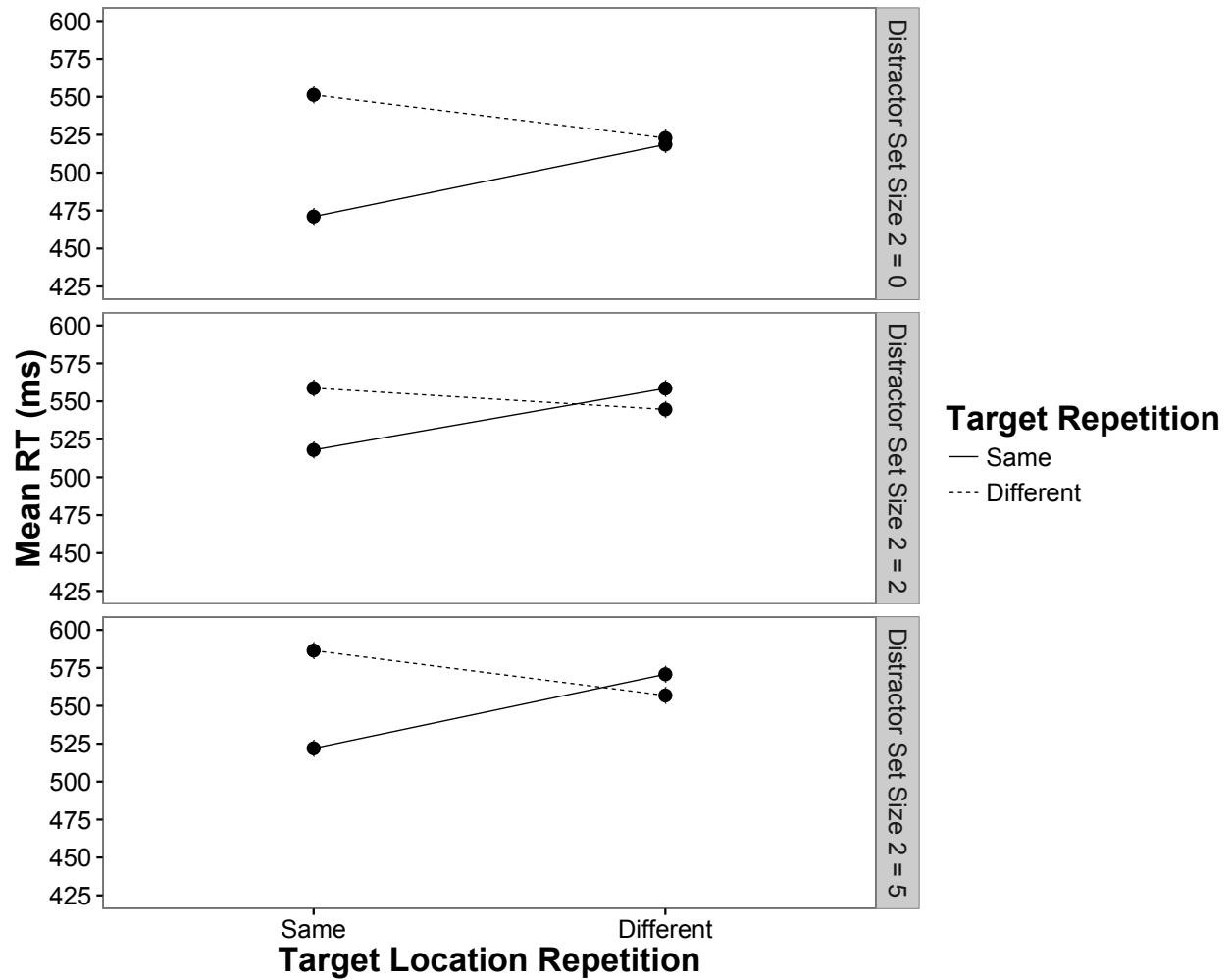


Figure 4. Mean response times (RTs) across all factorial combinations in Experiment 2B. Error bars are half Fisher's least significant differences (LSDs) computed from the mean squared error term of their interaction.

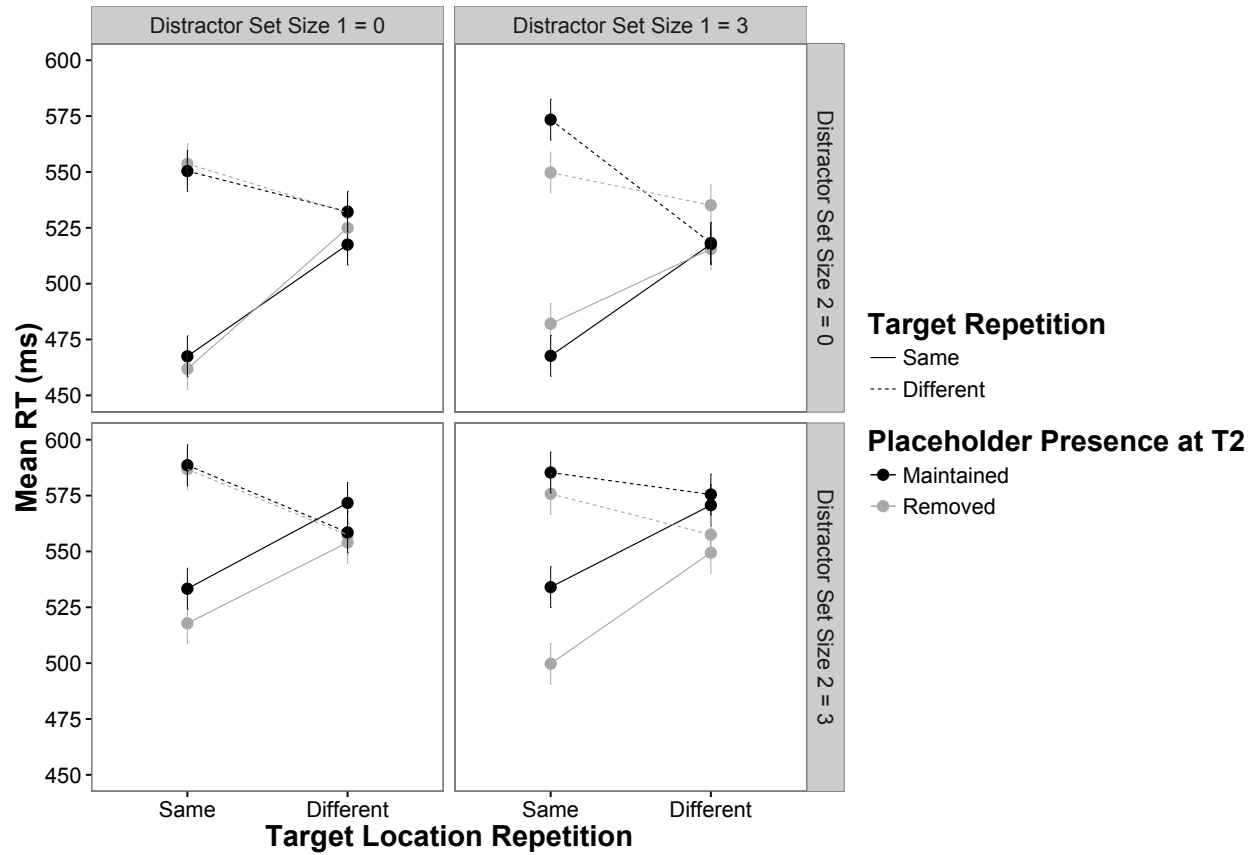


Figure 5. Mean response times (RTs) across all factorial combinations in Experiment 3. Error bars are half Fisher's least significant differences (LSDs) computed from the mean squared error term of their interaction.

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